

Claims

- [c1] 1. A method for registering a plurality of image sets, wherein each of the plurality of image sets comprises at least one image, and wherein each of the plurality of image sets contain spatially overlapping areas of an imaged subject with at least one of the remaining plurality of the image sets, the method comprising:
- selecting a reference image set and an evaluation image set from said plurality of image sets, wherein the evaluation image set is to be aligned with the reference image set;
 - selecting a methodology for comparing of the registration between the reference image set and the evaluation image set;
 - selecting one or more point locations on the evaluation image set for tracking image movement;
 - selecting one or more fixed reference points for comparison with the one or more point locations on the evaluation image set;
 - selecting type of transformation to apply to the evaluation image set for aligning the evaluation image set with the reference image set;
 - a) calculating quality of alignment between the reference image set and the evaluation image set using a selected quality of alignment methodology;
 - b) calculating a location value (C) from one or more points on the evaluation image set with respect to the selected one or more fixed reference points and storing the calculation in the memory;
 - c) calculating a next transformation to apply to the evaluation image;
 - d) applying the transformation to at least a subset of the evaluation image set;
 - e) calculating a convergence value (V) for the current iteration (i), and storing the convergence value to the memory;
 - f) performing steps (a), (b) (c), (d) and (e) until at least a predetermined number of correspondence calculation iterations have been performed; and
 - g) repeating steps (a), (b), (c), (d), and (e) if a total number of iterations (i) performed $\leq N$ and the convergence value (V) $\leq (t)$, wherein (t) is a threshold value.

- [c2] 2. The method for registering a plurality of image sets according to Claim 1,

wherein calculating correspondence further includes calculating Mutual Information between the reference image set and the evaluation image set.

- [c3] 3. The method for registering a plurality of images sets according to Claim 2, wherein the Mutual Information calculation further includes Stochastic sampling to compute the Mutual Information.
- [c4] 4. The method for registering a plurality of image sets according to Claim 2, wherein the image sets to be registered are capable of differing in at least one of temporally, modality, acquisition orientation, and dimensionality.
- [c5] 5. The method for registering a plurality of image sets according to Claim 1, wherein the image sets to be registered are capable of differing in at least one of temporally, modality, acquisition orientation, and dimensionality.
- [c6] 6. The method for registering a plurality of image sets according to Claim 1, wherein the selecting of point locations includes selecting corner points of the evaluation image set as the selected location points.
- [c7] 7. The method for registering a plurality of image sets according to Claim 1, further including using the selected corner points of the evaluation image set before the initial transformation as the fixed reference locations.
- [c8] 8. The method for registering a plurality of image sets according to Claim 1, wherein the location value (C) is an average distance between the one or more selected point(s) at the current iteration and the one or more fixed reference locations.
- [c9] 9. The method for registering a plurality of image sets according to Claim 1, wherein the convergence value (V) is calculated from the location values (C).
- [c10] 10. The method for registering a plurality of image sets according to Claim 9, wherein location value (C) is low pass filtered to remove noise.
- [c11] 11. The method for registering a plurality of image sets according to Claim 1, wherein location value (C) is low pass filtered to remove noise.
- [c12] 12. The method for registering a plurality of image sets according to Claim 1,

wherein the convergence value (V) for each iteration (i) is defined as a slope over the last L_2 iterations as

$$V(i) = (C(i) - C(i - L_2)) / L_2$$

- [c13] 13. The method for registering a plurality of image sets according to Claim 3, wherein the convergence value (V) for each iteration (i) is defined as a slope over the last L_2 iterations as

$$V(i) = (C(i) - C(i - L_2)) / L_2$$

- [c14] 14. The method for registering a plurality of image sets according to Claim 8, wherein the convergence value (V) for each iteration (i) is defined as a slope over the last L_2 iterations as

$$V(i) = (C(i) - C(i - L_2)) / L_2$$

- [c15] 15. The method for registering a plurality of images sets according to Claim 14, wherein convergence is obtained when absolute value of $(V) \leq t$ for at least L_3 of the last L_4 iterations such that $L_3 \leq L_4$.

- [c16] 16. The method for registering a plurality of images sets according to Claim 1, wherein convergence is obtained when absolute value of $(V) \leq t$ for at least L_3 of the last L_4 iterations such that $L_3 \leq L_4$.

- [c17] 17. The method for registering a plurality of image sets according to Claim 1, wherein the transformation of the evaluation image set is one of affine, rigid, deformable, and perspective.

- [c18] 18. The method for registering a plurality of image sets according to Claim 4, wherein the transformation of the evaluation image set is one of affine, rigid, deformable and perspective.

- [c19] 19. The method for registering a plurality of image sets according to Claim 1, wherein the transformation applied to the evaluation image set is determined by an optimization method.

[c20] 20. The method for registering a plurality of image sets according to Claim 19, wherein calculating correspondence further includes at least one of a Powell's method optimizer, a steepest gradient descent optimizer, a LBFGS optimizer, a Levenberg-Marquardt optimizer, a conjugate gradient optimizer, and a quasi-Newton optimizer.

[c21] 21. The method for registering a plurality of image sets according to Claim 1, wherein an image set comprises one or more images.

[c22] 22. The method for registering a plurality of image sets according to Claim 21, wherein the image set comprises data relating to functional measurements.

[c23] 23. The method for registering a plurality of image sets according to Claim 21, wherein the image set comprises data relating to anatomical data.

[c24] 24. The method for registering a plurality of image sets according to Claim 1, wherein the image set comprises data relating to functional measurements.

[c25] 25. The method for registering a plurality of image sets according to Claim 1, wherein the image set comprises data relating to anatomical data.

[c26] 26. The method for registering a plurality of image sets according to Claim 11, wherein the low-pass filter is defined as

$$C_l(i) = \frac{1}{L_1 - L_2} C(i)$$

, wherein L_1 is the length of the low-pass filter.

[c27] 27. The method for registering a plurality of image sets according to Claim 1, wherein the calculation of the convergence threshold (t) is dynamically determined based on the data.

[c28] 28. The method for registering a plurality of image sets according to Claim 27, wherein the calculation of the convergence threshold (t) is dynamically determined using a high-pass estimate of (V) to determine the noise level $C_h(i)$.

[c29] 29. The method for registering a plurality of image sets according to Claim 28, wherein the convergence threshold is defined as $t = f_1 + C_h(i) * f_2$.

- [c30] 30. The method for registering a plurality of image sets according to Claim 1, wherein the quality of alignment is voxel based.
- [c31] 31. The method for registering a plurality of image sets according to Claim 30, wherein the voxel based quality of alignment is further based on intensity of pixels of the image.
- [c32] 32. The method for registering a plurality of image sets according to Claim 31, wherein Mutual Information is utilized to determine quality of alignment.
- [c33] 33. The method for registering a plurality of image sets according to Claim 32, wherein Mutual Information further includes stochastic approximation.
- [c34] 34. The method for registering a plurality of image sets according to Claim 1, wherein the quality of alignment is feature based.
- [c35] 35. The method for registering a plurality of image sets according to Claim 34, wherein the feature based quality of alignment is further based on edges extracted from the image.
- [c36] 36. A system for registering a plurality of image sets, wherein each of the plurality of image sets comprises at least one image, and wherein each of the plurality of image sets contain spatially overlapping areas of an imaged subject with at least one of the remaining plurality of the image sets, the system comprising:
means for selecting a reference image set and an evaluation image set from said plurality of image sets, wherein the evaluation image set is to be aligned with the reference image set;
means for selecting a methodology for comparing the registration between the reference image set and the evaluation image set;
means for selecting one or more point locations on the evaluation image set for tracking image alignment;
means for selecting one or more fixed reference points for comparison with the one or more point locations on the evaluation image set;
means for selecting type of transformation to apply to the evaluation image set for aligning the evaluation image set with the reference image set;

a) means for calculating quality of alignment between the reference image set and the evaluation image set using the selected feature set;

b) means for calculating a location value (C) from one or more points on the evaluation image set with respect to the selected one or more fixed reference points and storing the calculation in the memory;

c) means for calculating a next transformation to apply to the evaluation image;

d) applying the transformation to at least a subset of the evaluation image set;

e) means for calculating a convergence value (V) for the current iteration (i), and storing the convergence value to the memory;

f) means for performing steps (a), (b) (c), (d) and (e) until at least L_5 correspondence calculation iterations have been performed;

g) repeating steps (a), (b), (c), (d), and (e) if a total number of iterations (i) performed $\leq N$ and the convergence value (V) $\leq (t)$, wherein (t) is a threshold value.

[c37] 37. The system for registering a plurality of image sets according to Claim 36, wherein calculating correspondence further includes calculating Mutual Information between the reference image set and the evaluation image set.

[c38] 38. The system for registering a plurality of images sets according to Claim 37, wherein the Mutual Information calculation further includes Stochastic sampling to compute the Mutual Information.

[c39] 39. The system for registering a plurality of image sets according to Claim 37, wherein the image sets to be registered are capable of differing in at least one of temporally, modality, acquisition orientation, and dimensionality.

[c40] 40. The system for registering a plurality of image sets according to Claim 36, wherein the image sets to be registered are capable of differing in at least one of temporally, modality, acquisition orientation, and dimensionality.

[c41] 41. The system for registering a plurality of image sets according to Claim 36, wherein the calculating location step further includes selecting corner points of the evaluation image set as the selected location points.

[c42] 42. The system for registering a plurality of image sets according to Claim 36,

further including using the selected corner points of the evaluation image set as the fixed reference locations before the initial transformation.

- [c43] 43. The system for registering a plurality of image sets according to Claim 36, wherein the location value (C) is an average distance between the one or more selected point(s) at the current iteration and the one or more fixed reference locations.
- [c44] 44. The system for registering a plurality of image sets according to Claim 36, wherein the convergence value (V) is calculated from the location value (C).
- [c45] 45. The system for registering a plurality of image sets according to Claim 36, wherein location value (C) is low pass filtered to remove noise.
- [c46] 46. The system for registering a plurality of image sets according to Claim 36, wherein the convergence value (V) for each iteration (i) is defined as a slope over the last M iterations as
- $$V(i) = (C(i) - C(i-M))/M$$
- [c47] 47. The system for registering a plurality of images sets according to Claim 47, wherein convergence is obtained when absolute value of $(V) \leq t$ for at least Q of the last L iterations such that $Q \leq L$.
- [c48] 48. The system for registering a plurality of image sets according to Claim 36, wherein the transformation of the evaluation image set is capable of being limited to one of affine, rigid and deformable.
- [c49] 49. The system for registering a plurality of image sets according to Claim 39, wherein the transformation of the evaluation image set is capable of being limited to one of affine, rigid and deformable.
- [c50] 50. The system for registering a plurality of image sets according to Claim 36, wherein an image set comprises one or more images.
- [c51] 51. The system for registering a plurality of image sets according to Claim 36, wherein the image set comprises data relating to functional measurements.

[c52] 52. The system for registering a plurality of image sets according to Claim 36, wherein the image set comprises data relating to anatomical data.

[c53] 53. The system for registering a plurality of image sets according to Claim 36, wherein the calculation of the convergence threshold (t) is dynamically determined based on the data.

[c54] 54. The system for registering a plurality of image sets according to Claim 55, wherein the convergence threshold is defined as $t = f_1 + C_h(i) * f_2$.

[c55] 55. A software product capable of directing a general purpose computer to register a plurality of image sets, wherein each of the plurality of image sets contain spatially overlapping areas of an imaged subject with at least one of the remaining plurality of the image sets, the software product comprising:
directing a general purpose computer to execute the steps of:
selecting a reference image set and an evaluation image set from said plurality of image sets, wherein the evaluation image set is to be aligned with the reference image set;
selecting a methodology for comparing the registration between the reference image set and the evaluation image set;
selecting one or more point locations on the evaluation image set for tracking image alignment;
selecting one or more fixed reference points for comparison with the one or more point locations on the evaluation image set;
selecting type of transformation to apply to the evaluation image set for aligning the evaluation image set with the reference image set;
a) calculating quality of alignment between the reference image set and the evaluation image set using the selected feature set;
b) calculating a location value (C) from one or more points on the evaluation image set with respect to the selected one or more fixed reference points and storing the calculation in the memory;
c) calculating a next transformation to apply to the evaluation image;
d) applying the transformation to at least a subset of the evaluation image set;
e) calculating a convergence value (V) for the current iteration (i), and storing

the convergence value to the memory;
 f) performing steps (a), (b) (c), (d) and (e) until at least L_5 correspondence calculation iterations have been performed;
 g) repeating steps (a), (b), (c), (d), and (e) if a total number of iterations (i) performed $\leq N$ and the convergence value (V) $\leq (t)$, wherein (t) is a threshold value.

[c56]

56. A system for registering image sets, the system comprising:
 a data processor, the data processor having a memory, wherein the data processor is capable of accessing and directing peripheral devices;
 a graphical user interface, wherein the graphical user interface is capable of interfacing with an navigating an imaging registration software product for registering image sets and wherein the software product is capable of instructing the data processor to perform instructions pursuant to the software product, the software product comprises:
 an instruction for selecting a reference image set and an evaluation image set from said plurality of image sets, wherein the evaluation image set is to be aligned with the reference image set;
 an instruction for selecting a methodology for comparing the registration between the reference image set and the evaluation image set;
 an instruction for selecting one or more point locations on the evaluation image set for tracking image alignment;
 an instruction for selecting one or more fixed reference points for comparison with the one or more point locations on the evaluation image set;
 an instruction for selecting type of transformation to apply to the evaluation image set for aligning the evaluation image set with the reference image set;
 a) an instruction for calculating quality of alignment between the reference image set and the evaluation image set using the selected feature set;
 b) an instruction for calculating a location value (C) from one or more points on the evaluation image set with respect to the selected one or more fixed reference points and storing the calculation in the memory;
 c) an instruction for calculating a next transformation to apply to the evaluation image;

- d) an instruction for applying the transformation to at least a subset of the evaluation image set;
- e) an instruction for calculating a convergence value (V) for the current iteration (i), and storing the convergence value to the memory;
- f) an instruction for performing steps (a), (b) (c), (d) and (e) until at least predetermined number of correspondence calculation iterations have been performed;
- g) an instruction for repeating steps (a), (b), (c), (d), and (e) if a total number of iterations (i) performed $\leq N$ and the convergence value (V) $\leq (t)$, wherein (t) is a threshold value.

[c57]

57. A system and method for registering a plurality of image sets and determining convergence, the system and the method comprising:
- a) calculating a convergence value (V) for a predetermined number of iterations (i), and storing each convergence value to the memory; and
 - b) repeating step (a), if a total number of iterations (i) performed $\leq N$ and the convergence value (V) $\leq (t)$, wherein (t) is a threshold value.

[c58]

58. A system and method for registering a plurality of image sets and determining convergence according to Claim 57, further including at least one of the steps of:
- selecting a reference image set and an evaluation image set from said plurality of image sets, wherein the evaluation image set is to be aligned with the reference image set;
 - selecting a methodology for comparing of the registration between the reference image set and the evaluation image set;
 - selecting one or more point locations on the evaluation image set for tracking image movement;
 - selecting one or more fixed reference points for comparison with the one or more point locations on the evaluation image set;
 - selecting type of transformation to apply to the evaluation image set for aligning the evaluation image set with the reference image set;
 - c) calculating quality of alignment between the reference image set and the evaluation image set using a selected quality of alignment methodology;

- d) calculating a location value (C) from one or more points on the evaluation image set with respect to the selected one or more fixed reference points and storing the calculation in the memory;
- d) calculating a next transformation to apply to the evaluation image; and
- e) applying the transformation to at least a subset of the evaluation image set.

[c59]

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